

## **Towards Offshore Testing Areas and Digital Twin of the Baltic Sea:** **Marine Data Analysis and Forecasting Applications**

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# Department of Marine Systems

## Numerical modelling

- operational forecast
- process studies

## In situ measurements

- experiments for process studies
- research vessel

## Operational measurement stations

- instrument/system development
- monitoring service

## Remote sensing

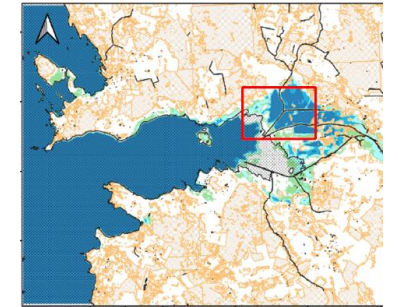
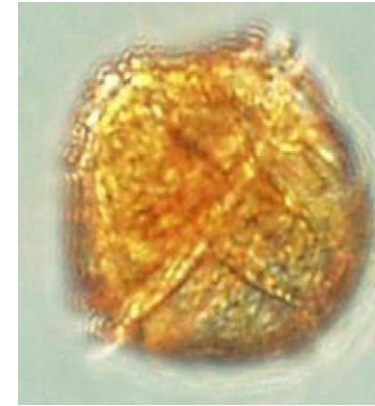
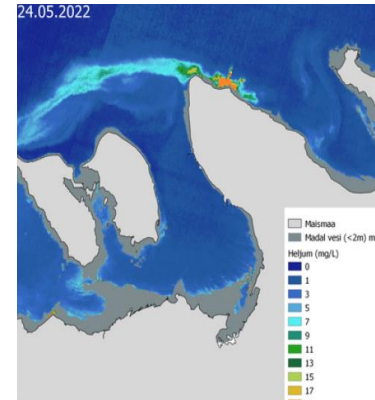
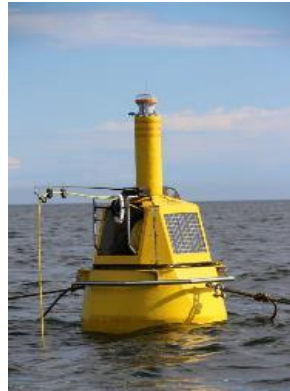
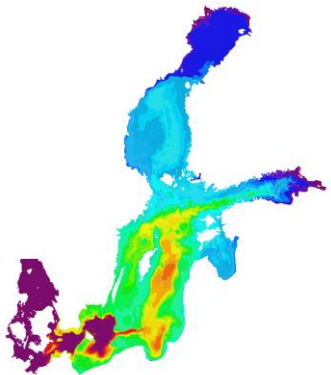
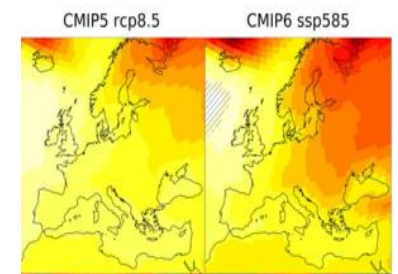
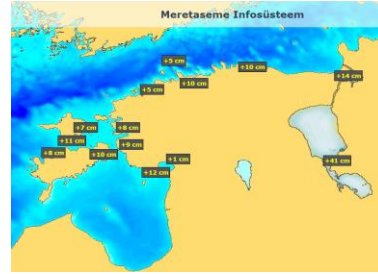
- Satellite (radar, optical)
- drone

## Marine ecology laboratory

- 18 certified methods

## Climate services

- Downscaling national climate projection
- Digital Twin applications



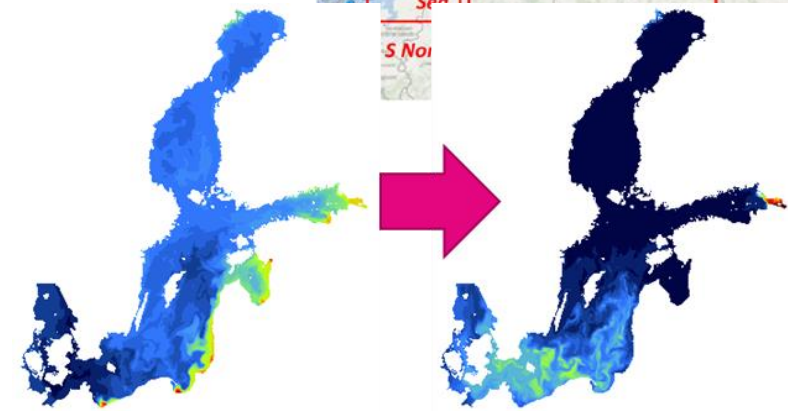
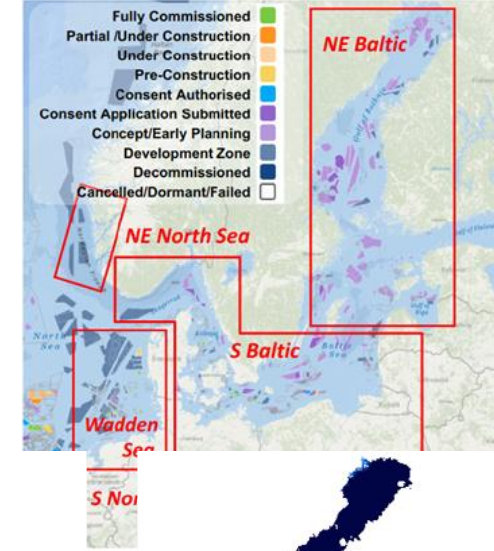


# User need for Digital Twin of the Ocean and marine test areas

- Need to **assess and forecast impacts** (minimize negative impacts) of offshore activities such as offshore construction, navigation, aquaculture, environmental impact assessment, safety-security at sea, etc.
- User groups and impact sectors (policy makers, state authorities, industry, researchers) need:
  - **(1) data driven solutions to make scientifically sound decisions related to the activities at sea and**
  - **(2) marine test area for validating and implementing novel technologies for empowering maritime sector**

## Challenge:

- (1) developing interactive data driven impact assessment/forecast models and sensing technologies to support DT services;
- (2) integrating different data sources to support knowledge based investment/management decisions;
- (3) agreeing on the location on test areas that are suitable for all counterparts;
- (4) equipment/investments for the test areas to assure effective experiments for marine industry.



# Digital Twin (DT) of the Earth/Ocean/Baltic Sea

- **Digital Twin is a dynamic and interactive information system that**
  - **provides a digital replica** of the past and current states of the ocean/sea, as accurately and timely as possible,
  - allows for **computing forecasts of future states** under nominal assumptions and based on the current replica, and
  - offers the capability to **investigate many hypothetical scenarios** under varying impact assumptions.

## Digital Replica ... **What now?**

*An integrated picture of the past and current states of Earth systems.*

## Forecasting ... **What next?**

*An integrated picture of how Earth systems will evolve in the future from the current state.*

## Impact Assessment ... **What if?**

*An integrated picture of how Earth systems could evolve under different hypothetical what-if scenarios.*



# Marine Test Area

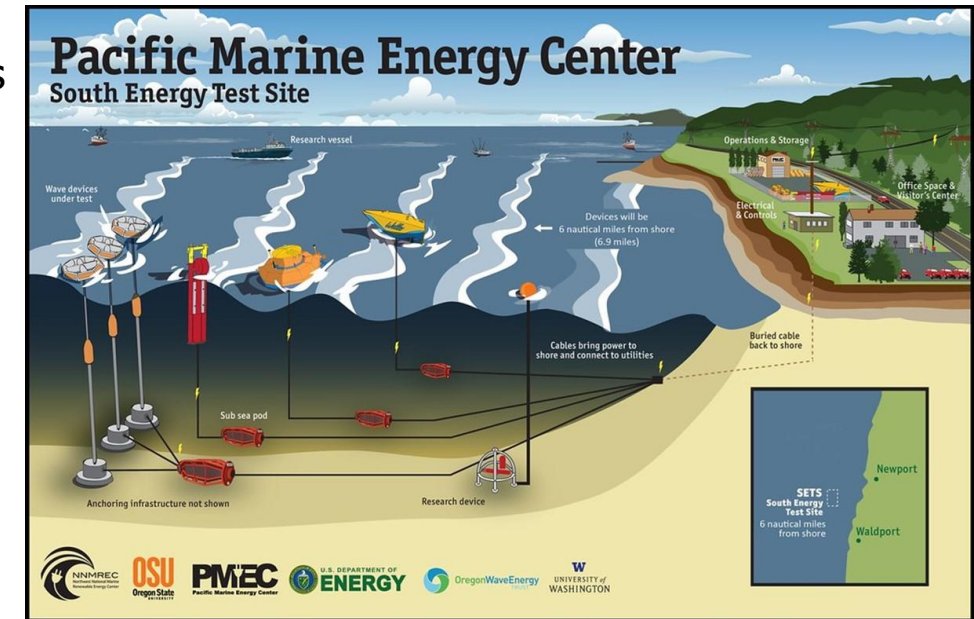
**Marine test area - a national facility that's helping to drive innovation in maritime sector.**

An important part of the test area is **dedicated support infrastructure**, which is located in various regions of the Estonian coastal sea and in sea areas managed by cooperation partners.

**Cooperation** between partner institutions: industry, academia and state

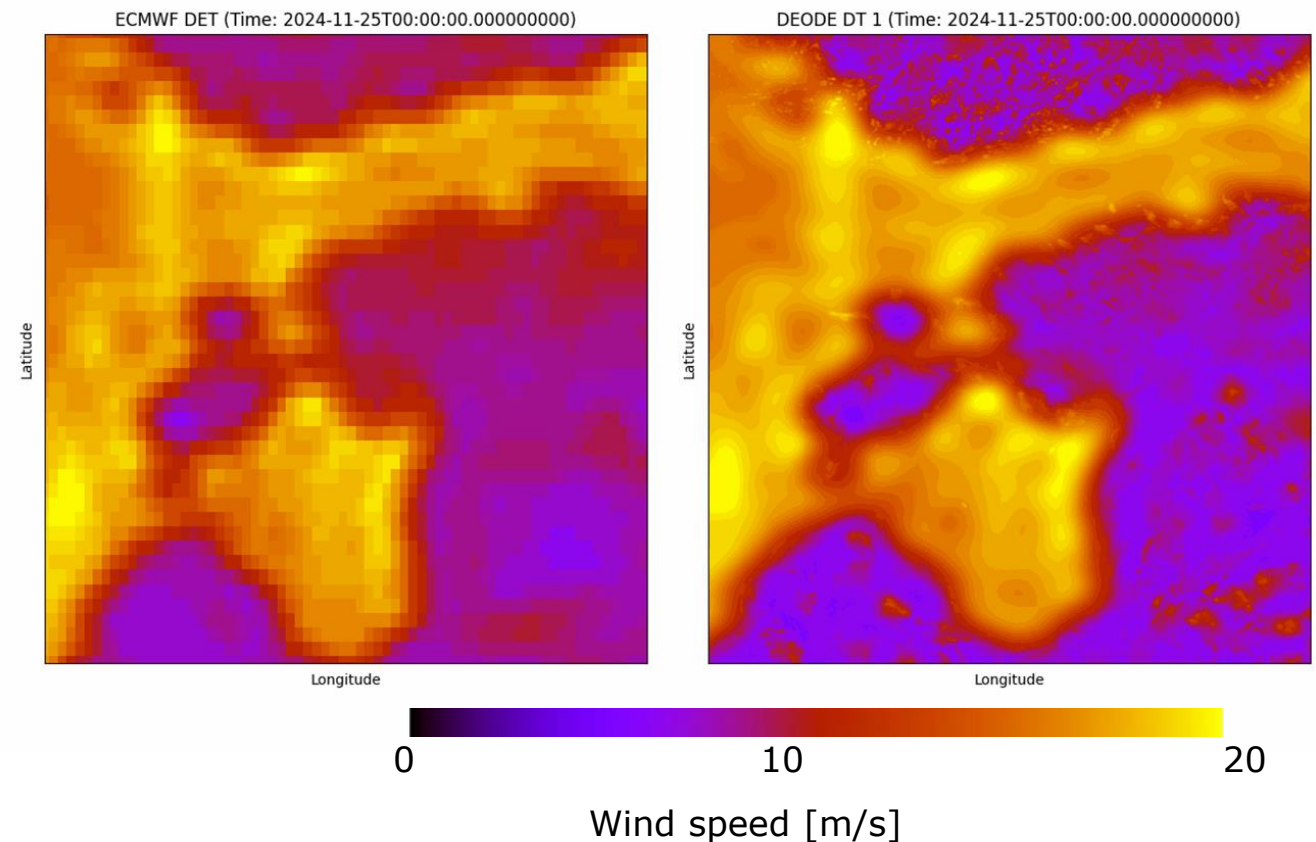
**Development of the concept of the complex** offshore test beds necessary for:

- developing and testing new marine technologies
- development and validation of digital twins.

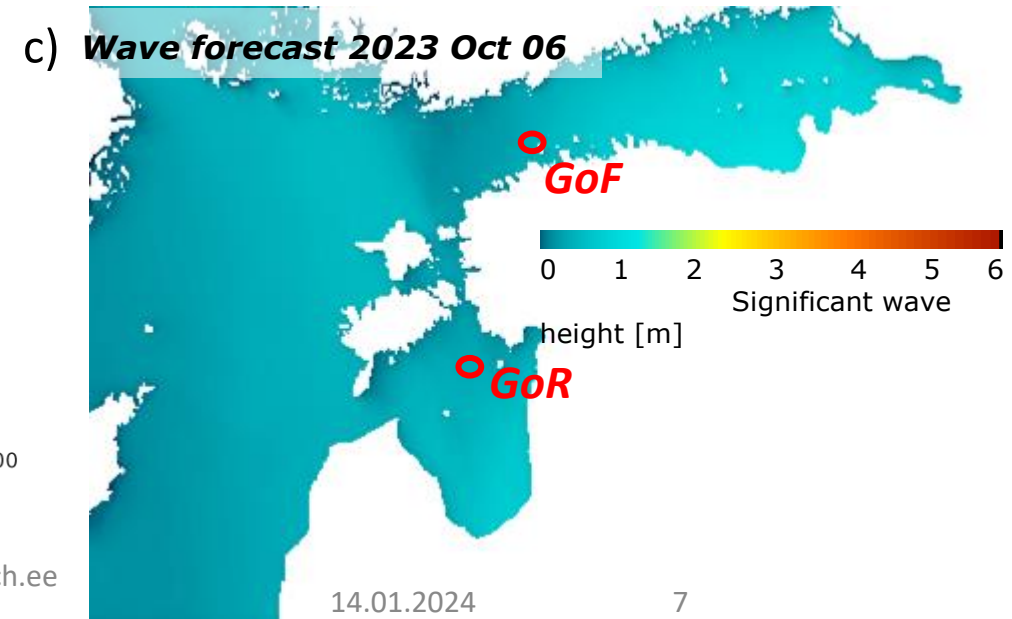




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- The diagram illustrates the organizational structure of the EC-MWF project. At the top, the European Union and EC-MWF are listed as the funding bodies. The project is led by a Contractor responsible for project coordination, METEO FRANCE. Below the Contractor are Subcontractors responsible for scientific coordination, including the Norwegian Meteorological Institute and DMI. A large semi-circular arc connects the Contractor to a wide array of participating institutions and research centers, which are organized into two columns. The left column includes institutions like ScaphiCore Austria, FMH, SMHI, ALUT, and others. The right column includes institutions like CINEC, GIV, INRAO, and others. The bottom of the diagram lists additional partners and funding sources, including the Norwegian Meteorological Institute, DMI, and various research centers like FMA and TERN.



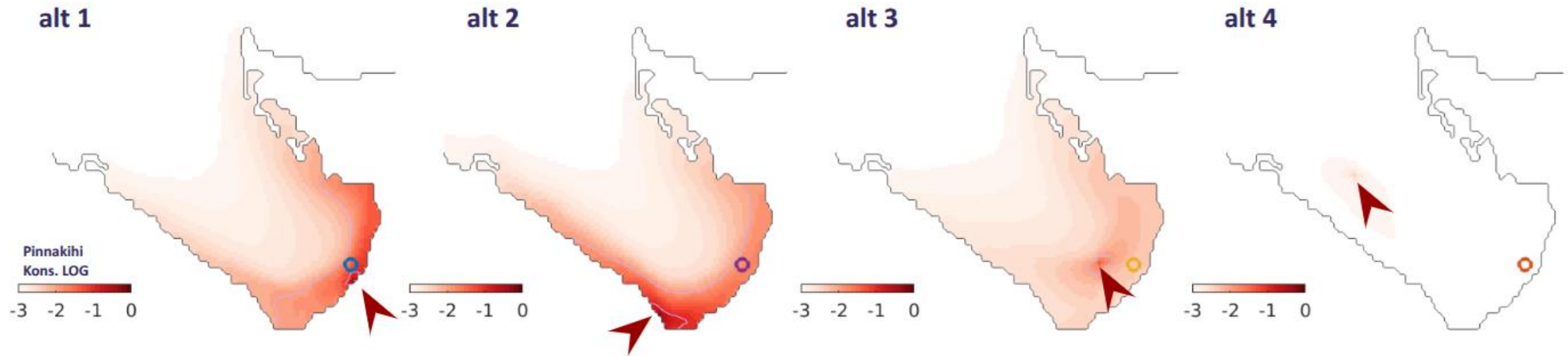
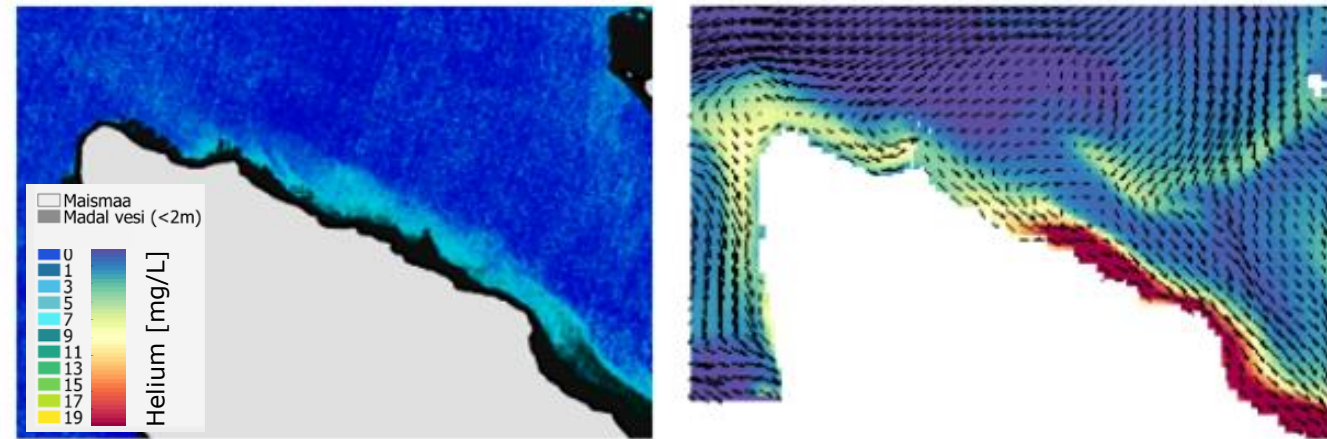
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# Coastal water quality and erosion

## Port constructions and water outlet

- Assessing potential impacts of new coastal developments i.e. what-if-scenarios
  - estimating LNG quay impacts to water quality and coastal erosion
  - Kopli stormwater discharge impact area: choosing discharge locations based on different scenarios (locations).

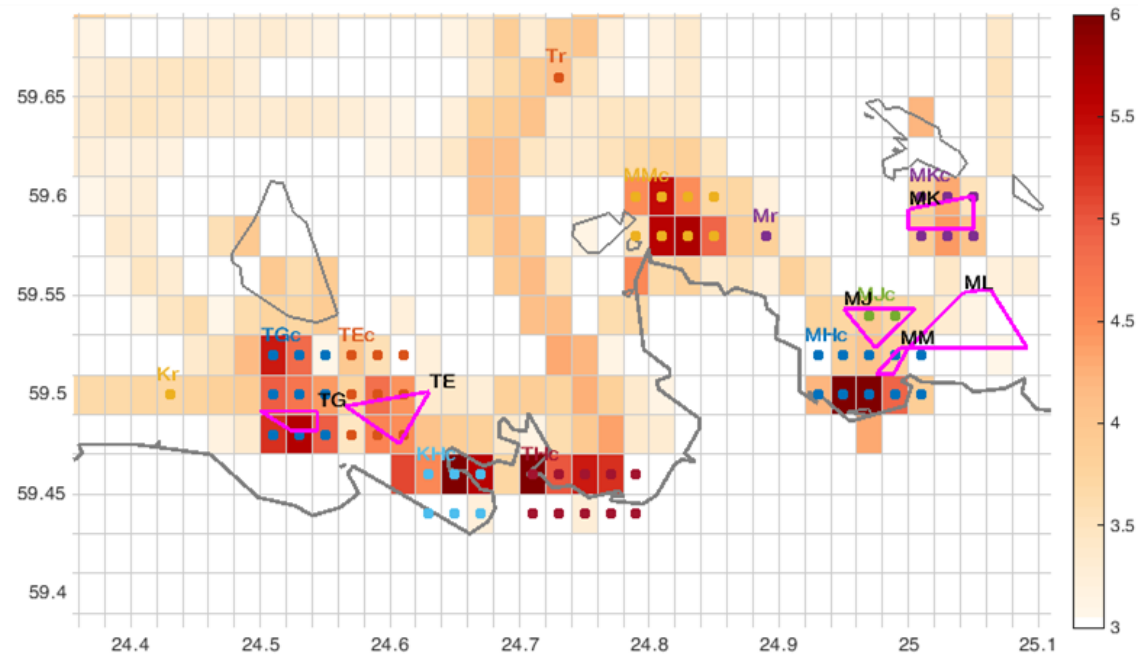




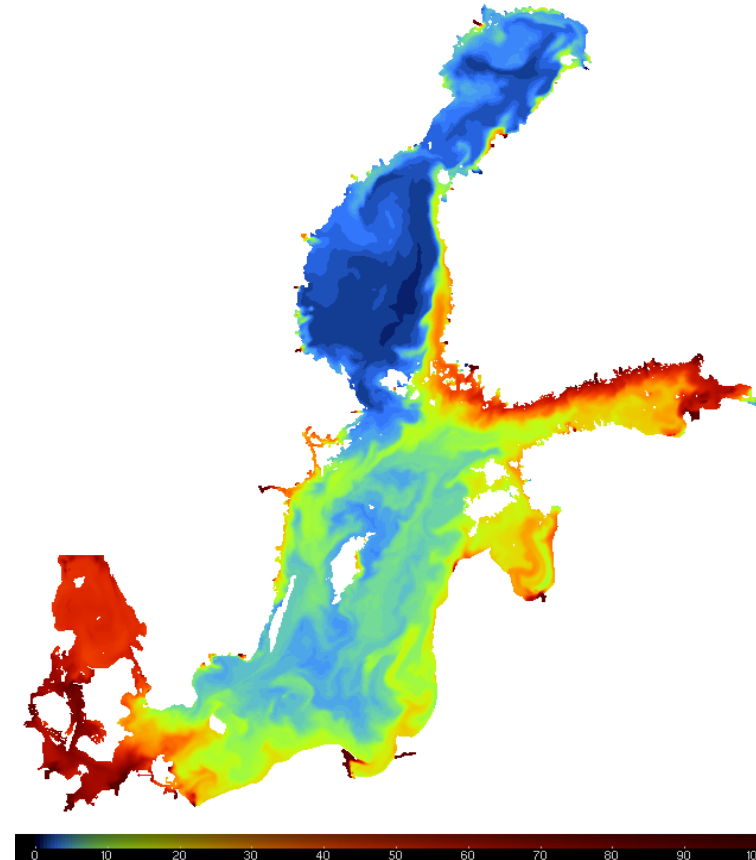
# Contaminants from shipping

## Antifouling paint impact

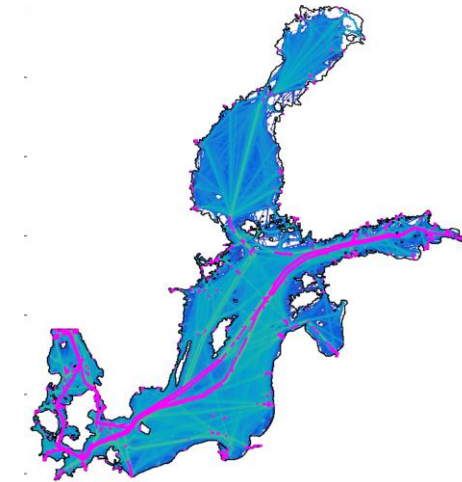
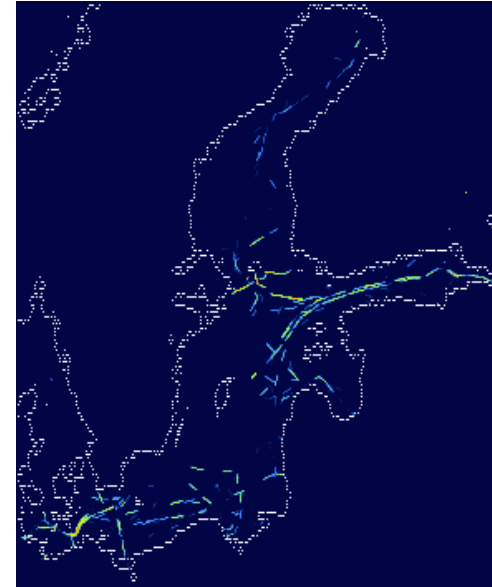
- Contaminants from the shipping
- Cases: Baltic Sea // Tallinn Bay



Vase koormus kattumisvastastest värvidest aastal 2020 [ $\log_{10} g$ ] ja määruusega ette nähtud STS/punkerdamise alad (lilla) (a).



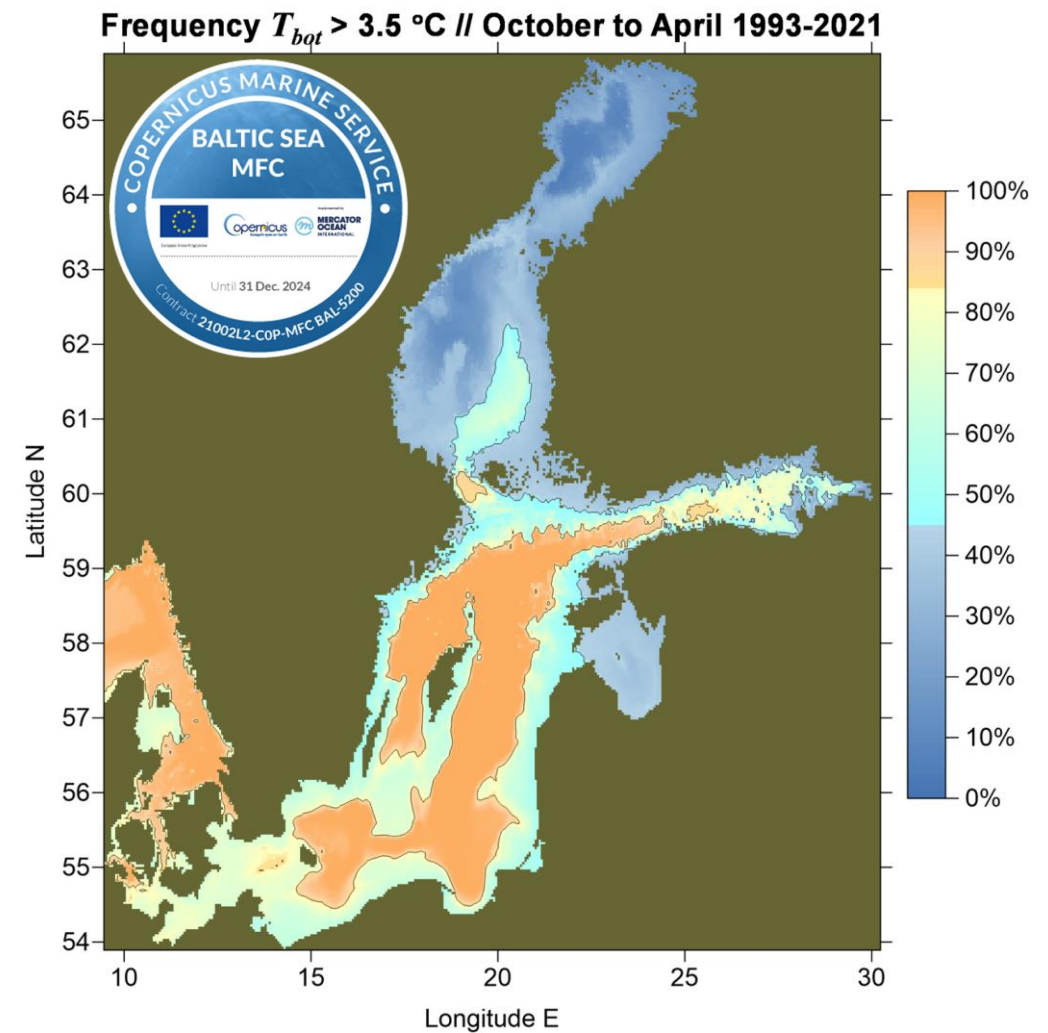
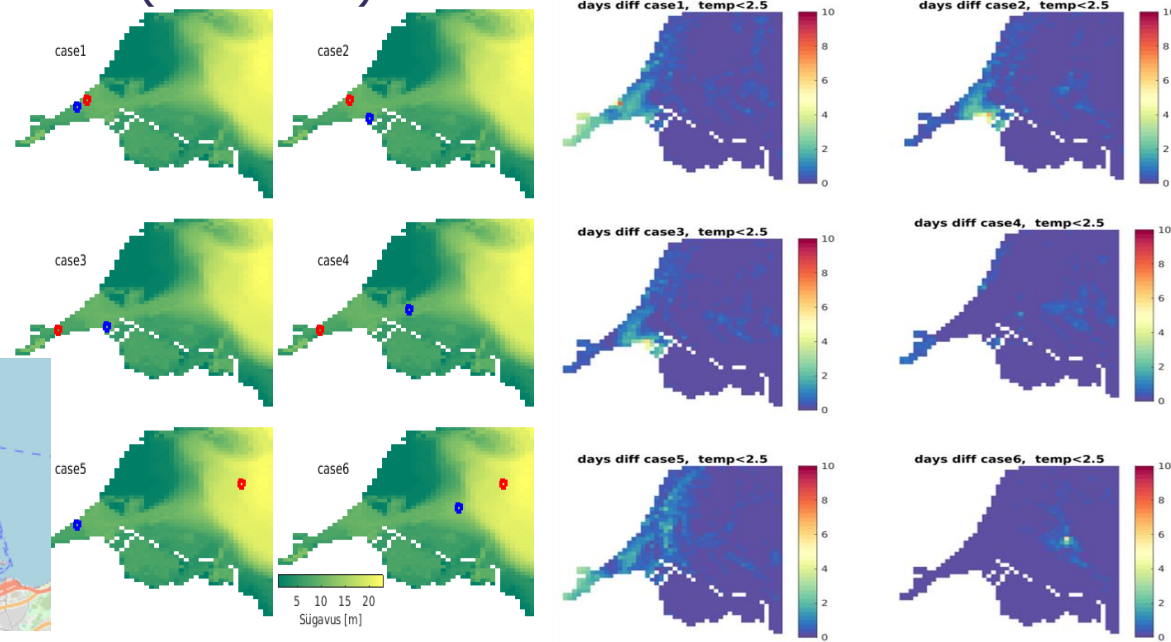
Vase kontsentratsioon pinnakihis, mis on tingitud laevade kaitsevärvidest



# Energy potential analysis

## Marine heat energy - 3D

- Finding the suitable deepwater thermal properties for residential heating
- What-if cases for water intake and outlet: Estonian Coastal sea Hundipea. Location of intake location and temporal availability of thermal resource ( $>2.5$  °C)



Elken, J., Maljutenko, I., Lagemaa, P., Uiboupin, R., and Raudsepp, U.: Oceanographic preconditions for planning seawater heat pumps in the Baltic Sea – an example from the Tallinn Bay, Gulf of Finland, in: 8th edition of the Copernicus Ocean State Report (OSR8), 2024



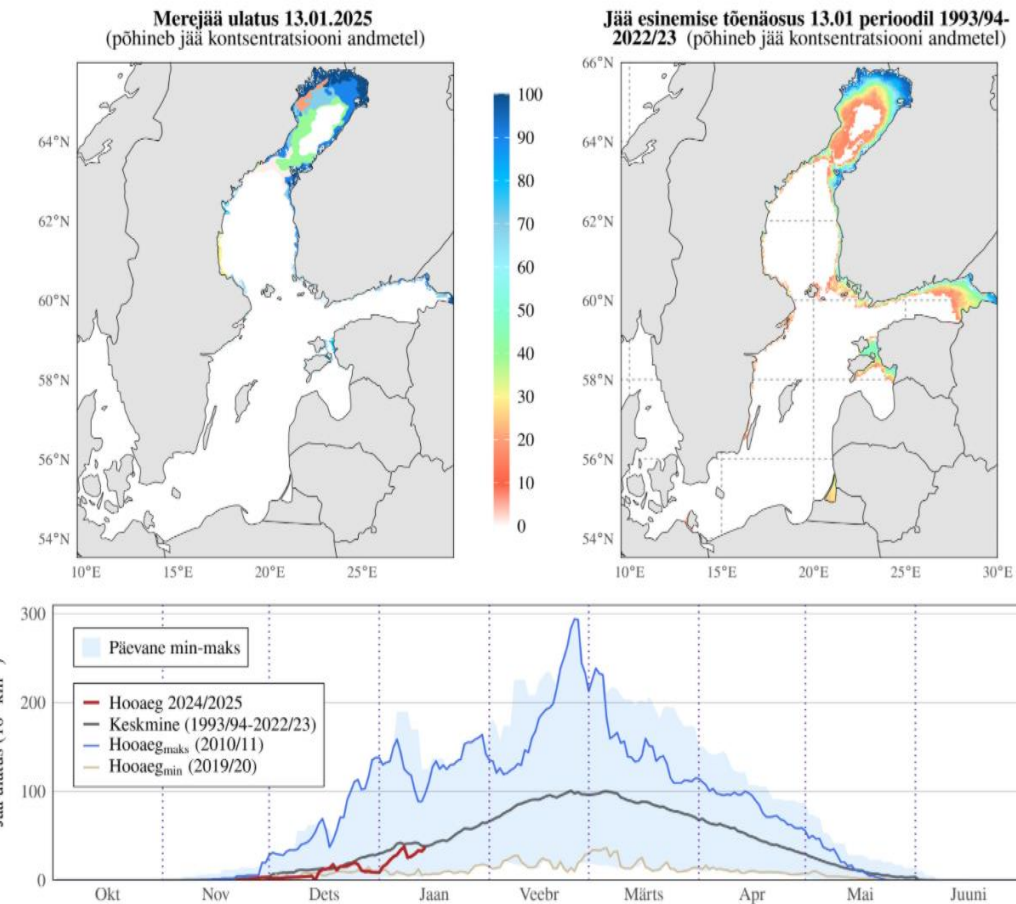
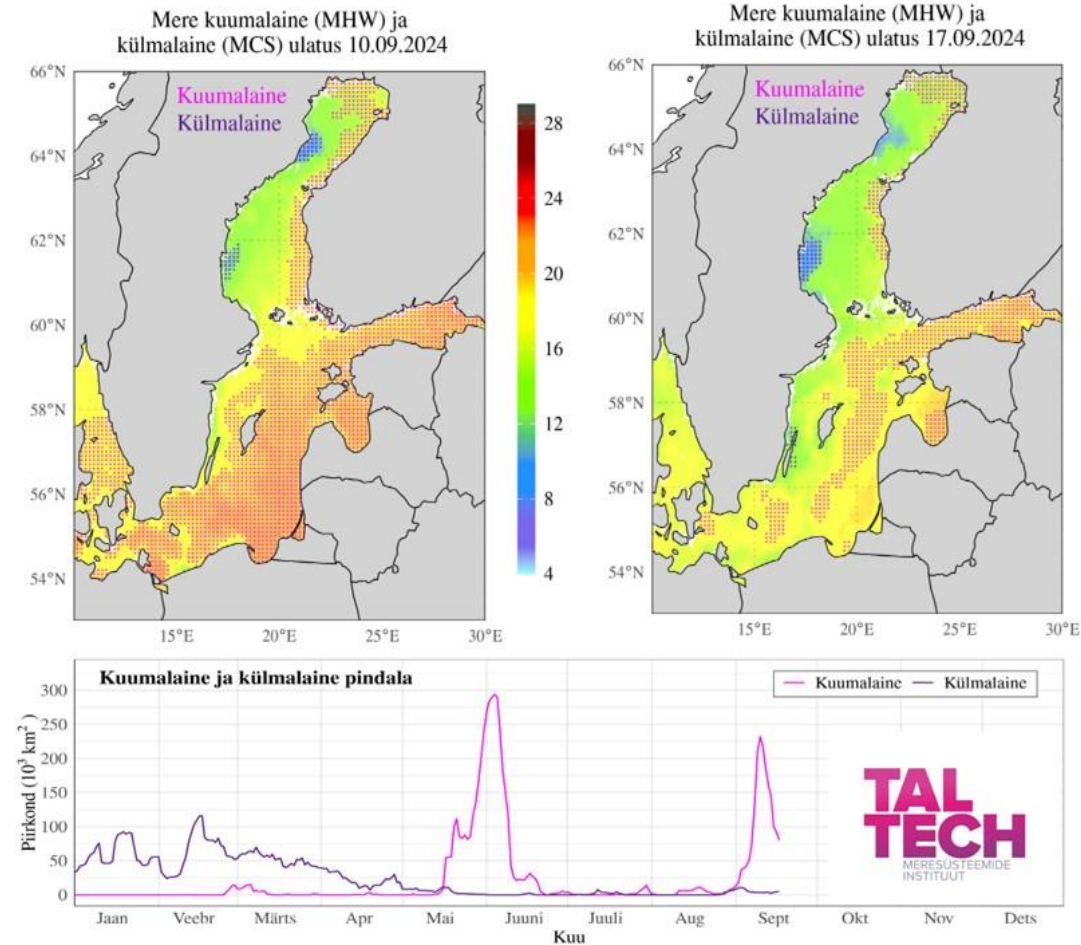
# Climate Services

Daily update of regional marine heatwave extent and ice extent

(cmems.msi.ttu.ee)



Kliima teenus: jääga kaetud ala



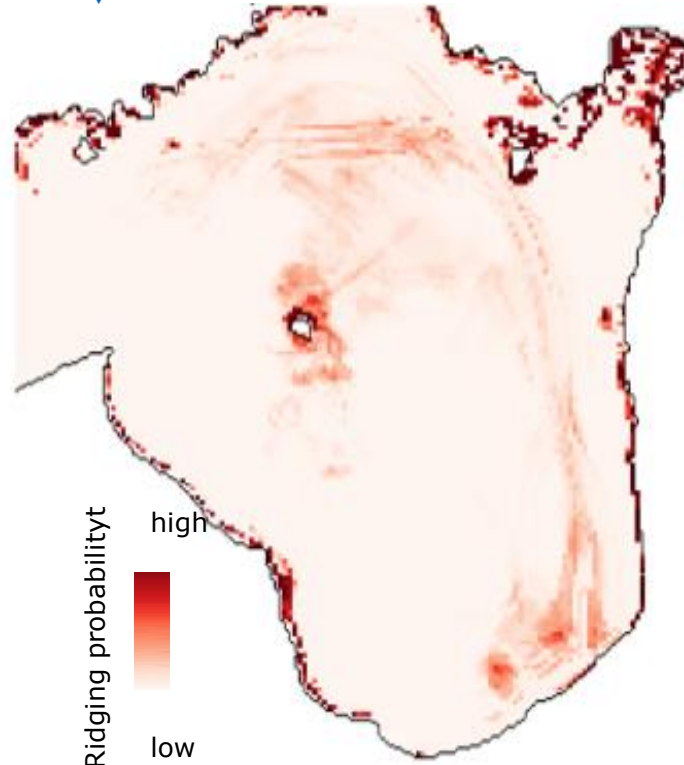
# Sea ice impact on offshore constructions

## Offshore construction impact on ice field

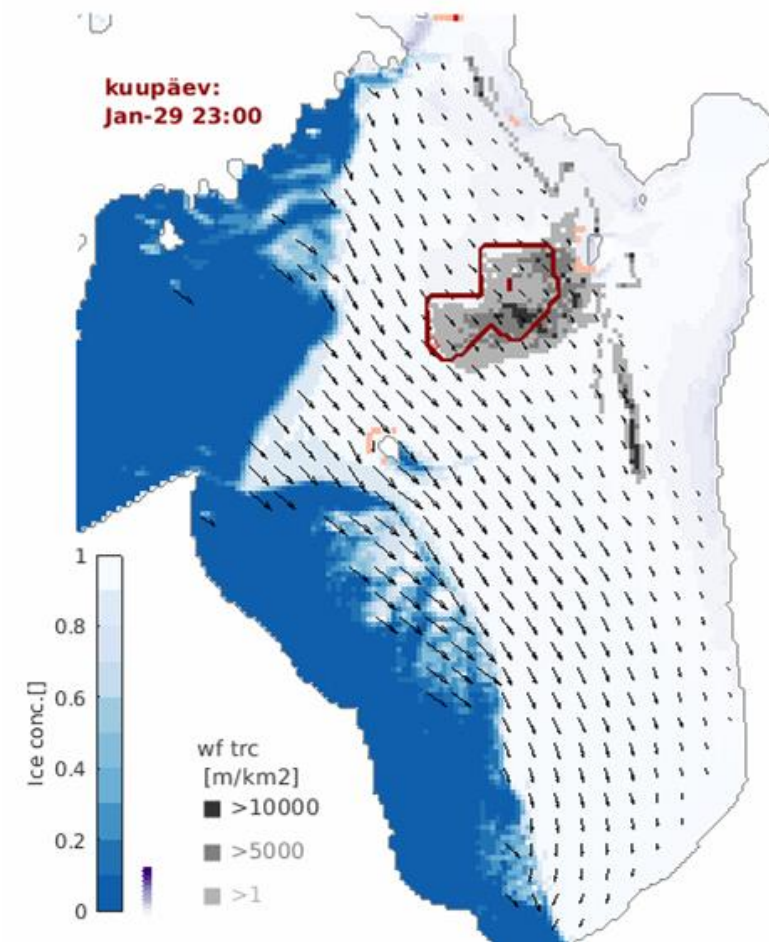
- Simulating sea ice ridge probability in Gulf of Riga based on Climate\_DT data
- Case study of sea ice deformation in the gulf of Riga affecting the offshore construction.



**NOCOS DT**  
NORDIC CRYOSPHERE DIGITAL TWIN



**TerraDT**  
Digital Twin of Earth system for Cryosphere,  
Land surface and related interactions



Gulf of Riga 2011 February  
Case study of the ice drift through  
WindFarm development area

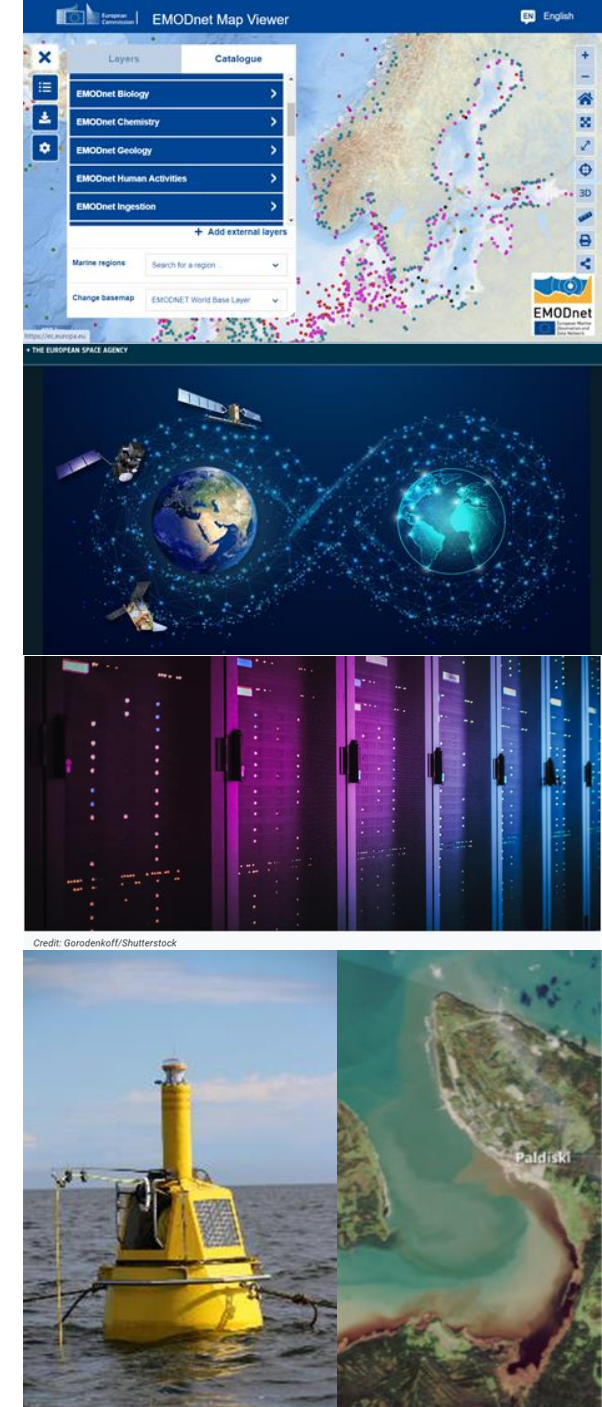


# Key message

**Cross-sectoral Digital Twin of the Baltic Sea and national Marine Test Areas for technology development are a “MUST BE” to support the maritime industry and sustainable use of marine environment.**

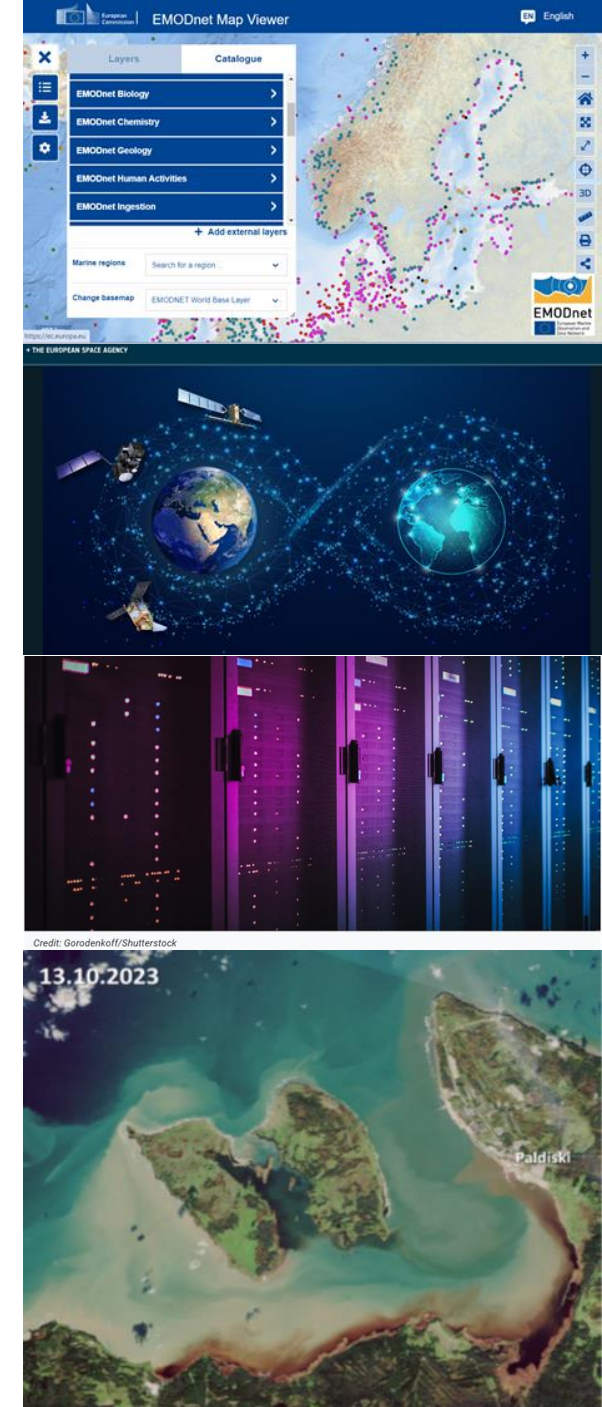
We need to:

- (1) develop interactive data driven impact assessment/ forecast models and sensing technologies;
- (2) develop data integration methods to support knowledge based investment/management decisions;
- (3) agree on the location on test areas (mini DTs) that are suitable for all counterparts;
- (4) equipment/investments for the test areas to assure effective experiments for marine industry.



# Conclusions on DTs

- DT's combine monitoring, forecasting and „what-if scenarios“ to assess and predict potential impacts related to activities at sea.
- DT's contain wide range of datasets:
  - from operational to climate time scales
  - from prices in situ observations to high resolution satellite data
- Direction on extensive use of AI/ML solutions and HPC resources.
- There is a need for various impact models that address the specific needs of impact sectors:
  - off-shore construction, MSP, navigation, disaster management, security, adaption to climate change etc.
- Strong need for regional co-operation to develop DTOs (including sectoral impact models and applications) for Baltic Sea.

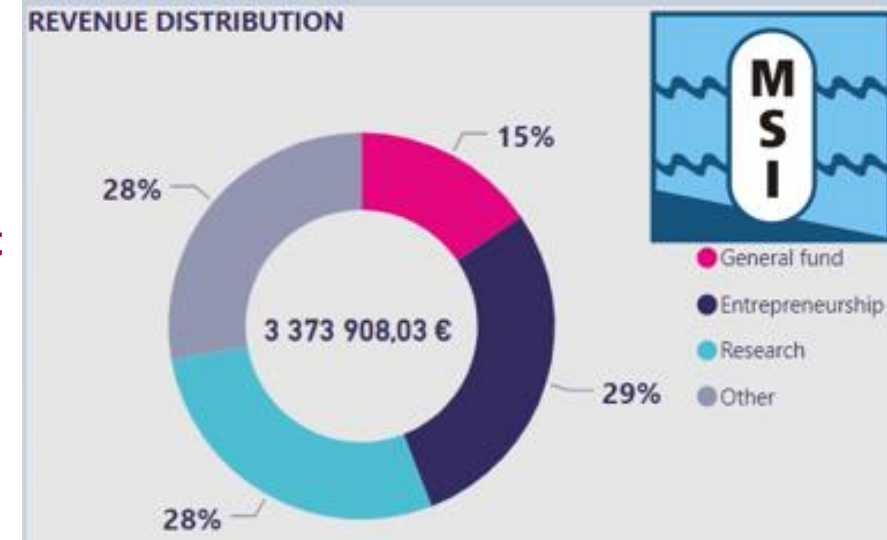




# Department of Marine Systems (MSI) at TalTech

Department of Marine Systems is a oceanographic and atmospheric R&D unit that:

- (1) conducts on process studies to identify cause-effect relations,
- (2) develops marine monitoring and forecasting services and
- (3) contributes to sectoral science based higher education



## Structure/divisions

- Division of marine physics
- Division of modelling and remote sensing
- Marine ecology lab

## Research groups have been formed based on the divisions

- Research Group on Dynamics of Gradient Systems
- Research Group on Modelling and Remote Sensing of Marine Dynamics

- Staff:** ca 50 persons, including 21 PIs with PhD degree and 11 PhD students
- What do we do?**
  - Process studies of marine environment
  - Operational monitoring and forecasting systems to support activities at sea
  - Big data reanalysis for maritime sector
  - Atmospheric physics and meteorology (incl. climate modelling)
  - Marine ecology and chemistry (microplastci, environmental DNA, ecotoxicology)
- Implementing methods:** *in situ* measurements, autonomous measurements and operational monitoring, numerical modelling, certified lab analysis, remote sensing methods.